Measurements of Black Carbon and Ozone Using Unmanned Aerial Vehicles.

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5th Annual California Climate Change Conference

Scripps Institution of Oceanography

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Outline

- UAVs as a tool for atmospheric measurements

- California AUAV Air Pollution Profiling Study
  - Aerosol, black carbon, and ozone

Advantages of Using Lightweight AUAVs

- Complement manned aircraft missions
- Inexpensive, routine operation
- Fly coordinated missions with multiple aircraft
- Can fly in risky environments
- Can operate from remote locations (ships, islands, etc.)

ACR Manta

Weight - 23 kg (takeoff)
Wingspan - 2.7 meters
Cruise velocity - 35 m/s
Payload - 5 kg
Flight duration - 5+ hours
Autonomous GPS flight
Satellite communication link
Auto Take-off and Landing

The Maldives Autonomous Unmanned Aerial Vehicle Campaign (MAC)

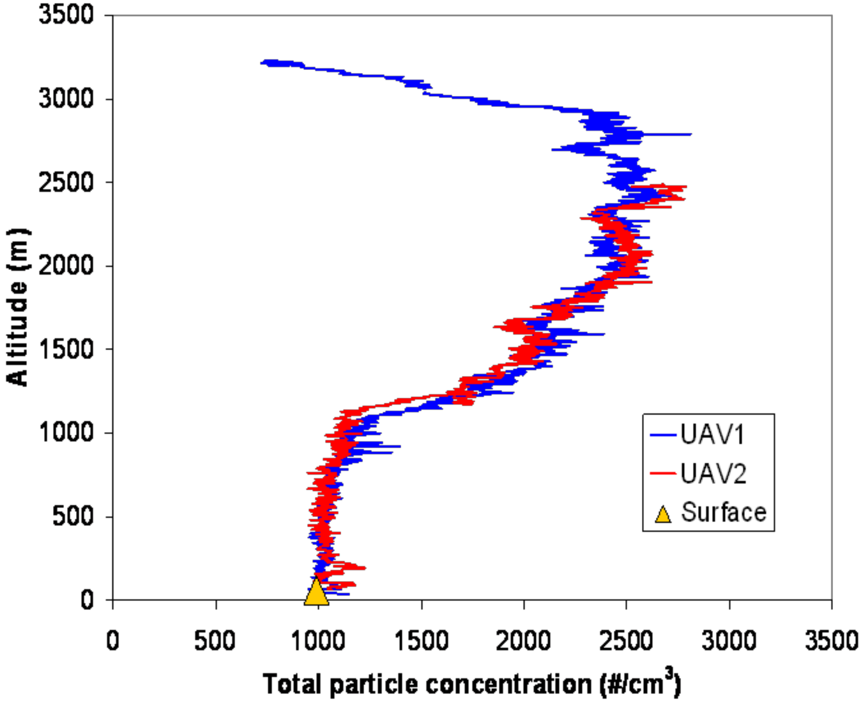
06 March - 01 April, 2006

(Funded by NSF, NASA & NOAA)

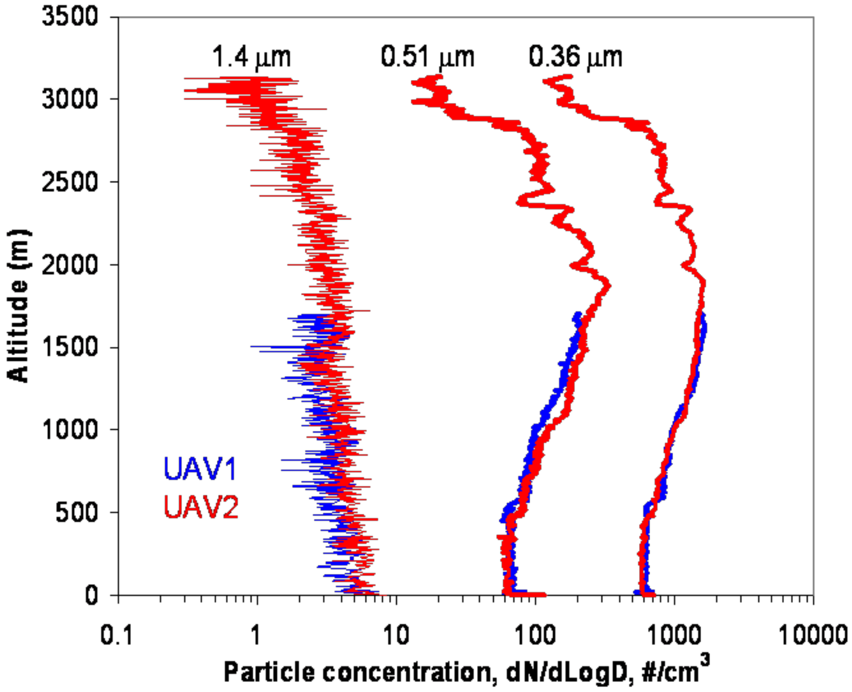
PI: V Ramanathan

Validation of Airborne Packages

Total Particles



Size Distribution



Corrigan et al., 2008

UAVs have arrived as a tool for studying the atmosphere.

Ramanathan et al, Nature 2007

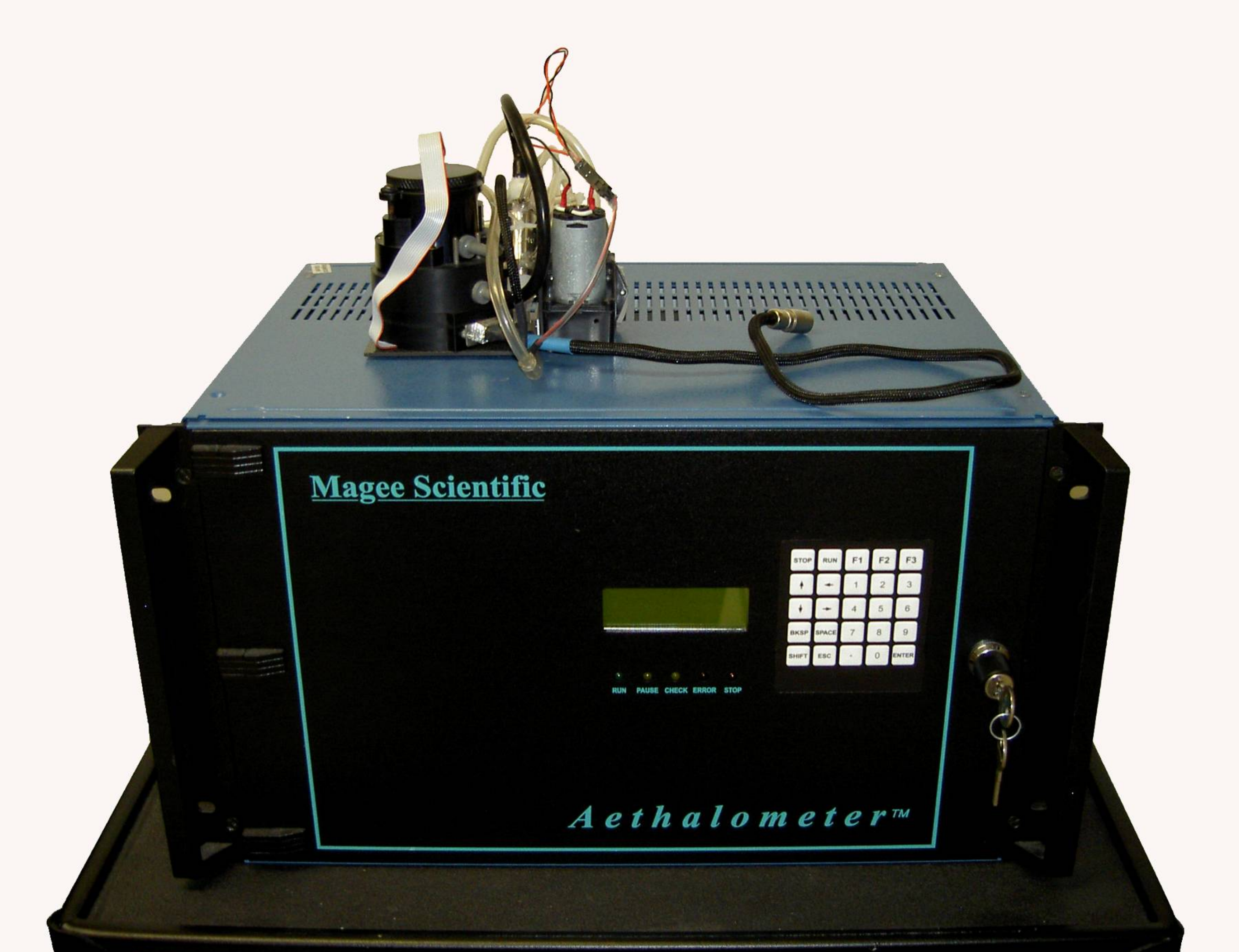
MAC Stacked UAV Flight Configuration

3 km asl

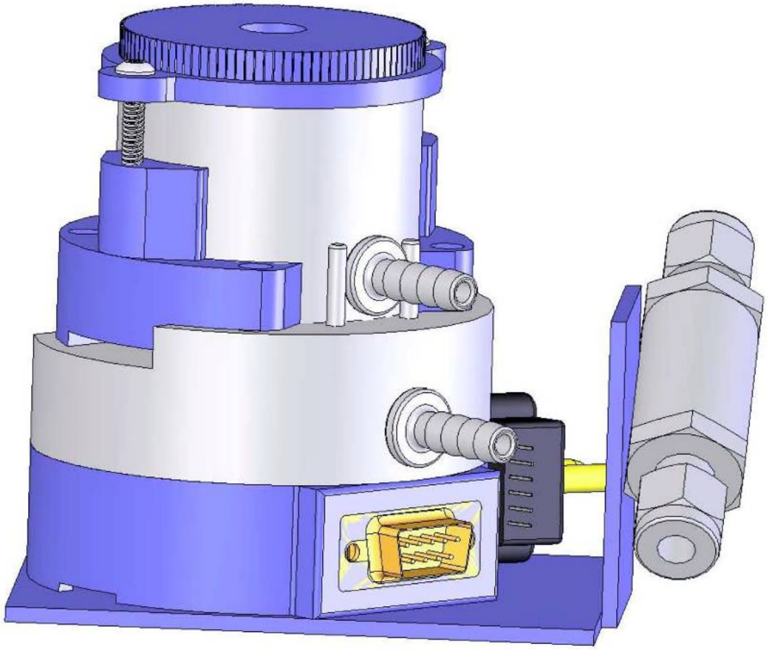
In cloud

100 m below cloud

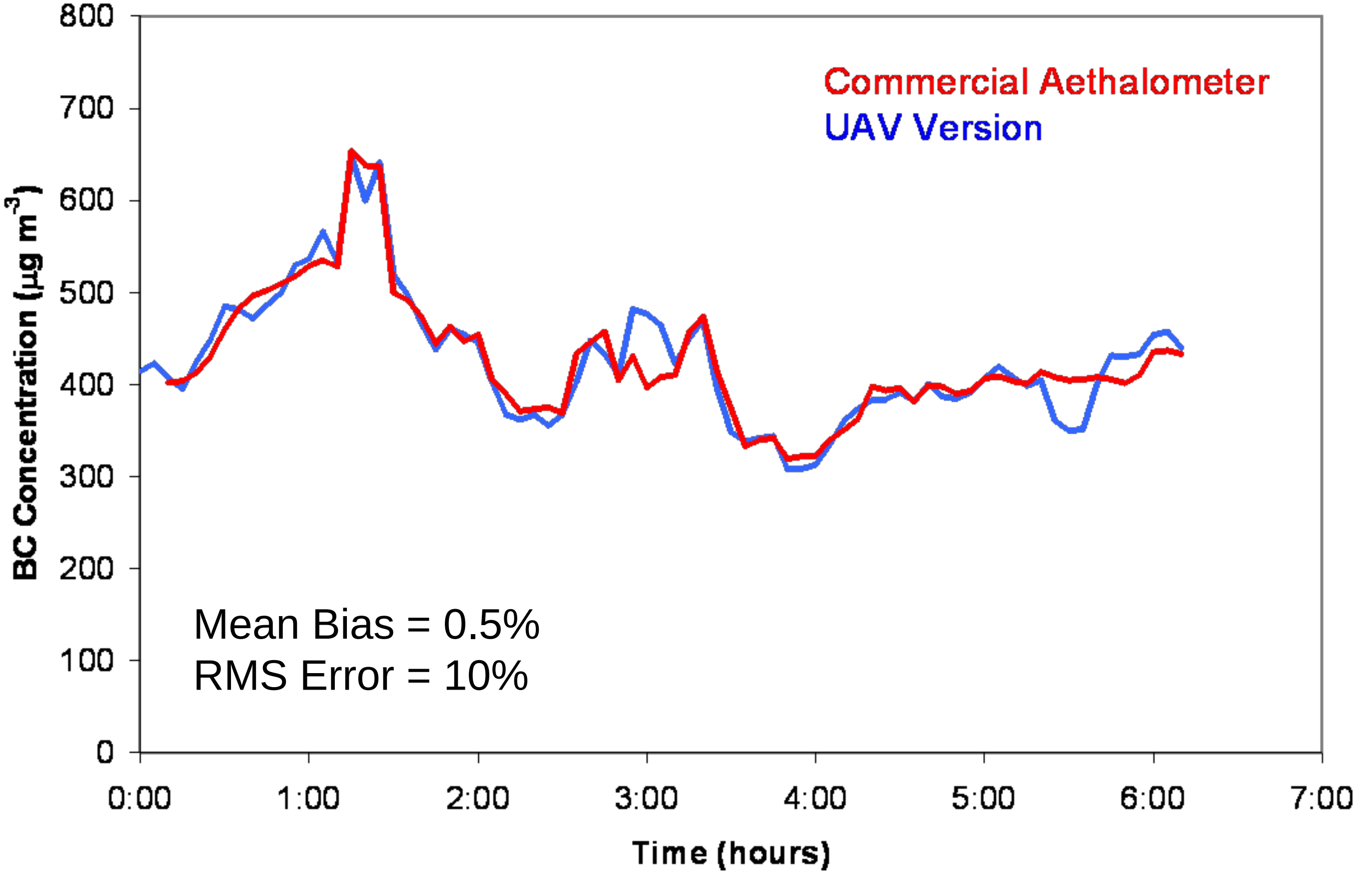
Surface observations


Magee Scientific
STOP
RUN
F1
F2
F3
1
2
3
4
5
6
BKSP
SPACE
7
8
9
SHIFT
ESC
.
0
ENTER
RUN
PAUSE
CHECK
ERROR
STOP
Aethalometer™

CAD Modeling to Fit Payloads

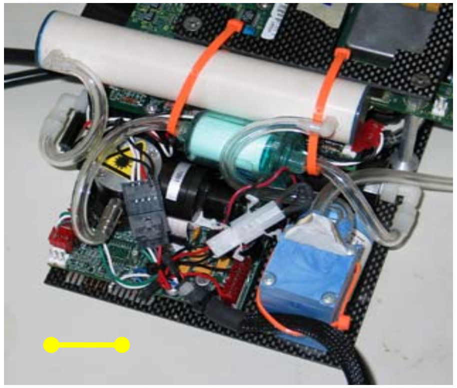


Laboratory Comparison of UAV and Commercial Aethalometer



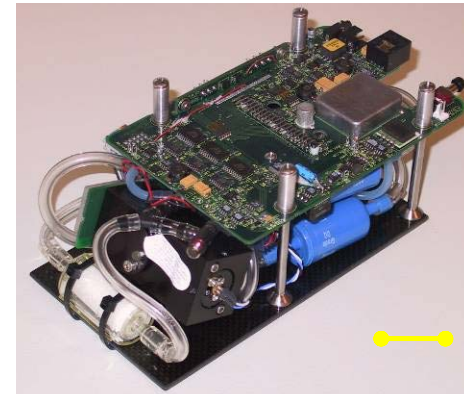
Corrigan et al, 2008.

Miniaturized Instruments for UAV



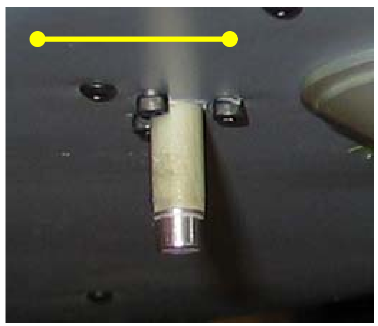
Optical Particle Counter (580 g)
→ N_{OPC}; $0.3 < D_p < 3\ \mu m$

[=] 1 inch

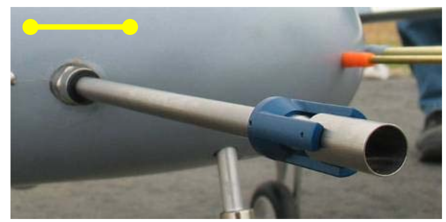


Condensation Particle Counter (870 g) → N_{CN}; $D_p > 10$ nm

Aethalometer (820 g)
→ absorbing aerosol



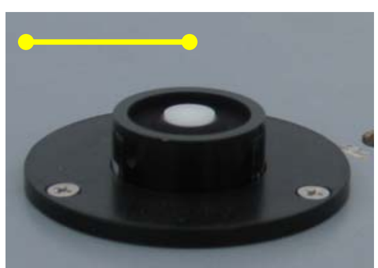
T/RH probe (50 g)
→ Temperature & RH



Aerosol inlet & splitter (150 g)
→ unbiased aerosol sampling

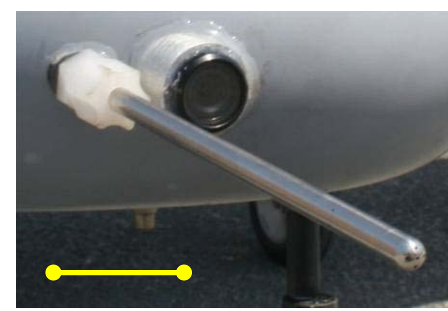
Cloud Droplet Spectrometer (1.4 kg) → distr. $1 < D < 50\ \mu m$

Pyranometer (190 g)
→ irradiance 0.3 – 2.8 μm



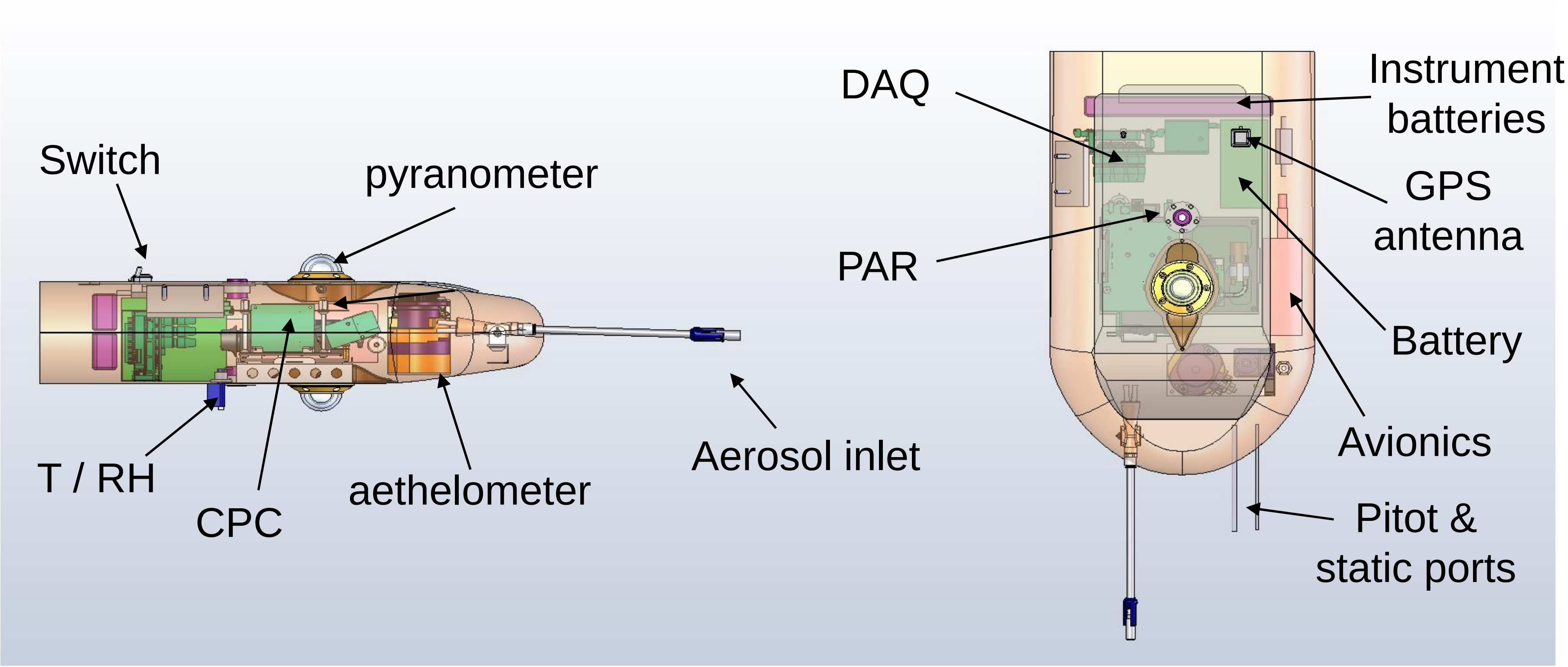
PAR radiometer (45 g)
→ irradiance 400 – 700 nm

LWC probe (450 g)
→ Cloud water (g m^{-3})



Video camera (280 g)
→ cloud targeting

CAD Modeling of Payload



Greg Roberts, 2005

CAPPS

(California AUAV Air Pollution Profiling Study)

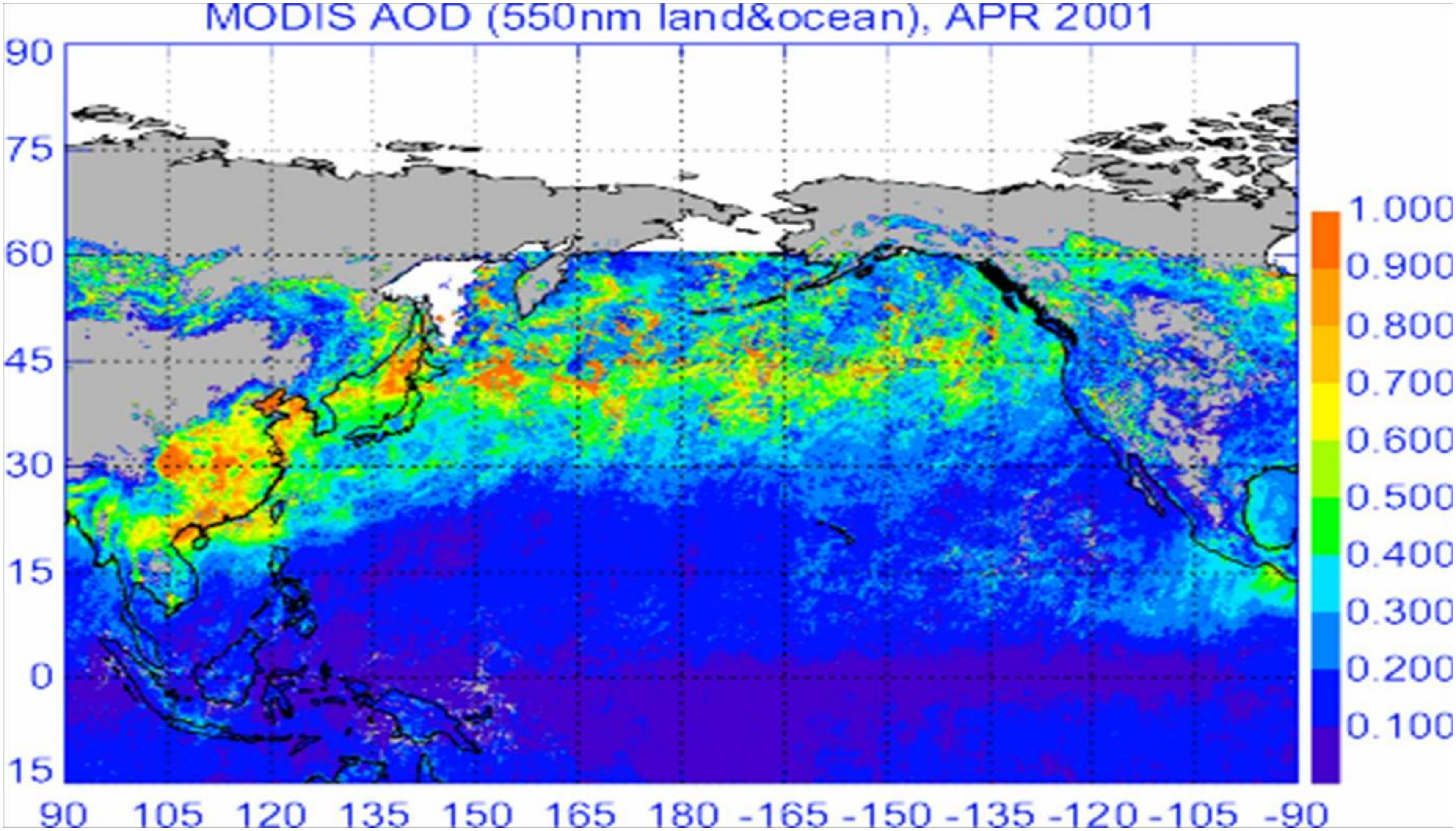
Funded by California Energy Commission.

- Collect a seasonal record of aerosol, black carbon and ozone pollution concentrations from surface up to 12,000 feet asl.

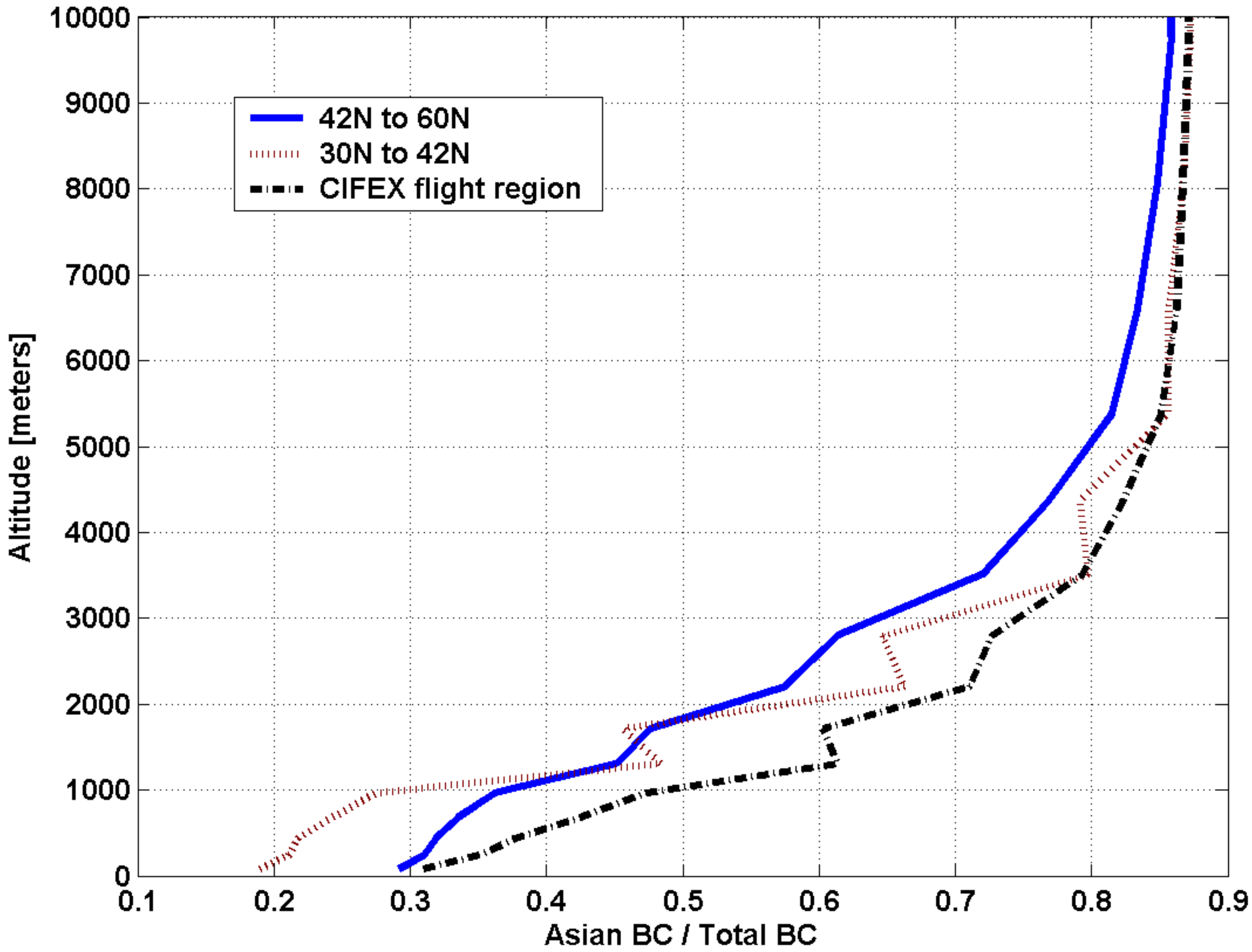
- California generated pollution vs. long-range pollution from other regions.

- Look at the impact of pollution layers on radiative forcing to quantify the amount of solar dimming and heating rates.

Asian particulate pollution transported to North America



Influence of Asian black carbon increases with altitude.



Hadley et al., 2006

Measurements for CAPPS

- Aerosol Number Concentration
- Aerosol Size Distribution (0.3 – 3 μm)
- Aerosol Absorption/Black Carbon Concentration
- Ozone
- Solar Flux
- Temperature, Pressure, Relative Humidity

Sampling Site – NASA Dryden

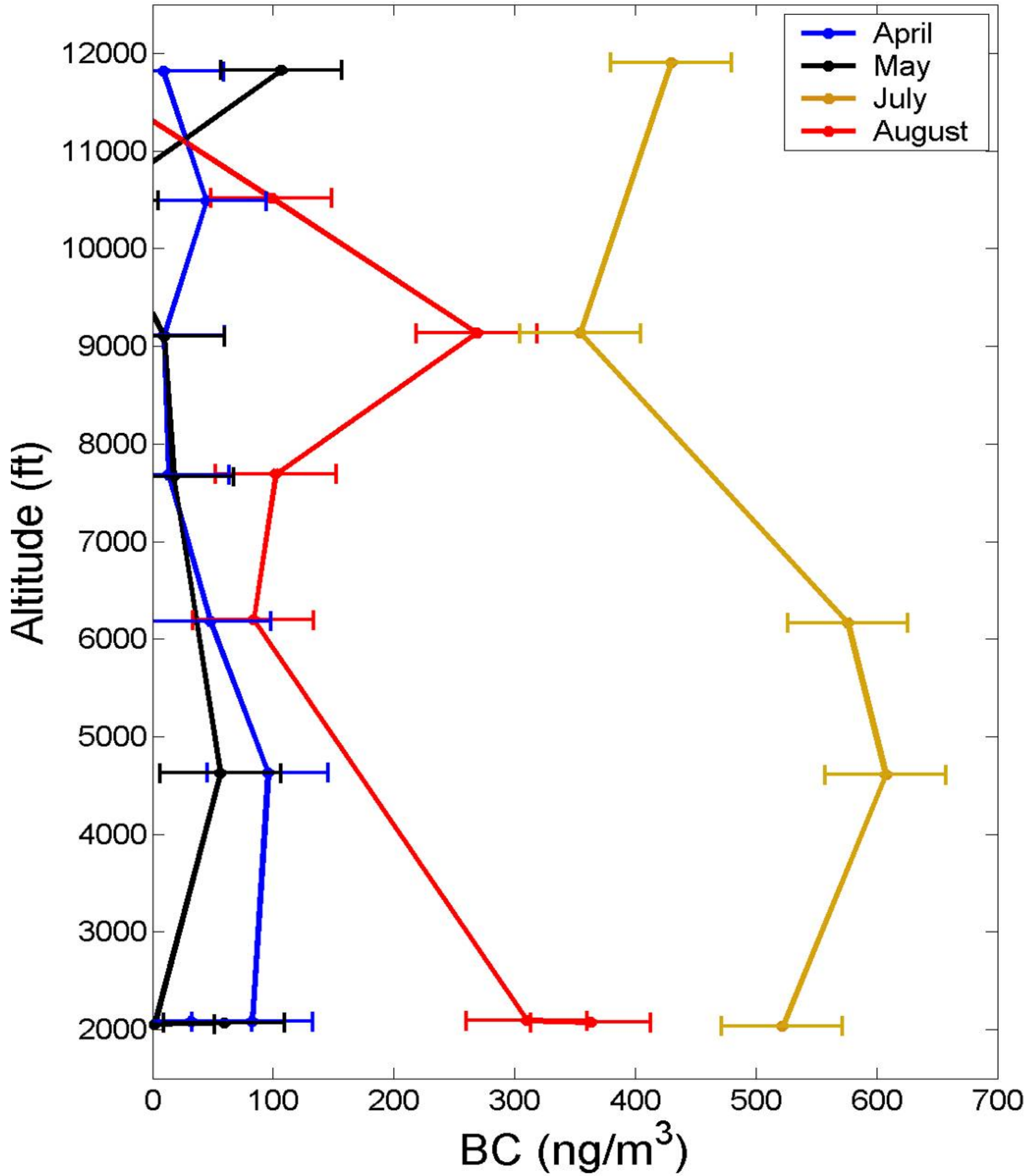
Edwards Air Force Base in Mojave Desert

CAPPS Missions

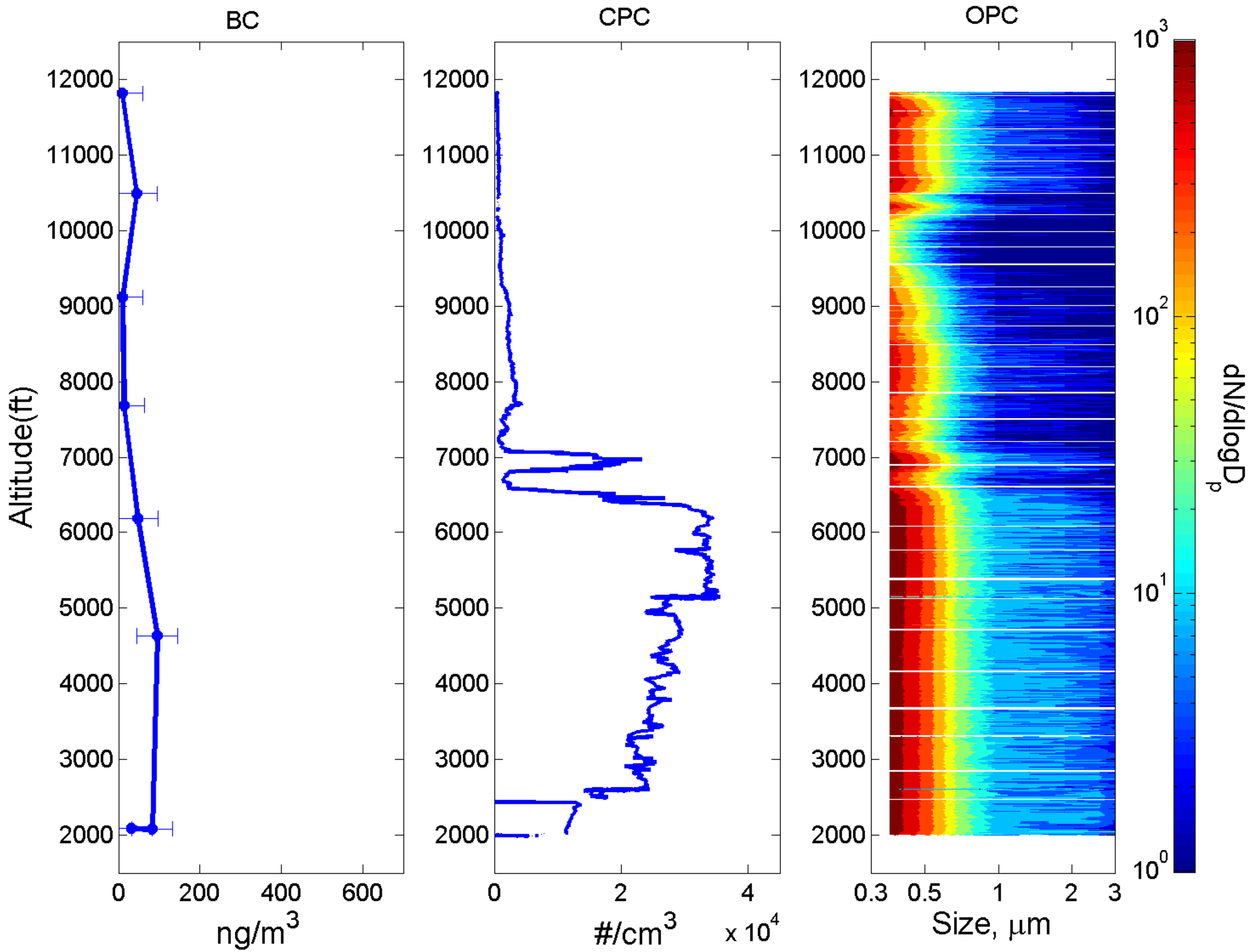
- Flights started in early April
- Attempting 1 to 2 flights per month

- Aerosol Flights to date = 10
- Ozone Flights to date = 4

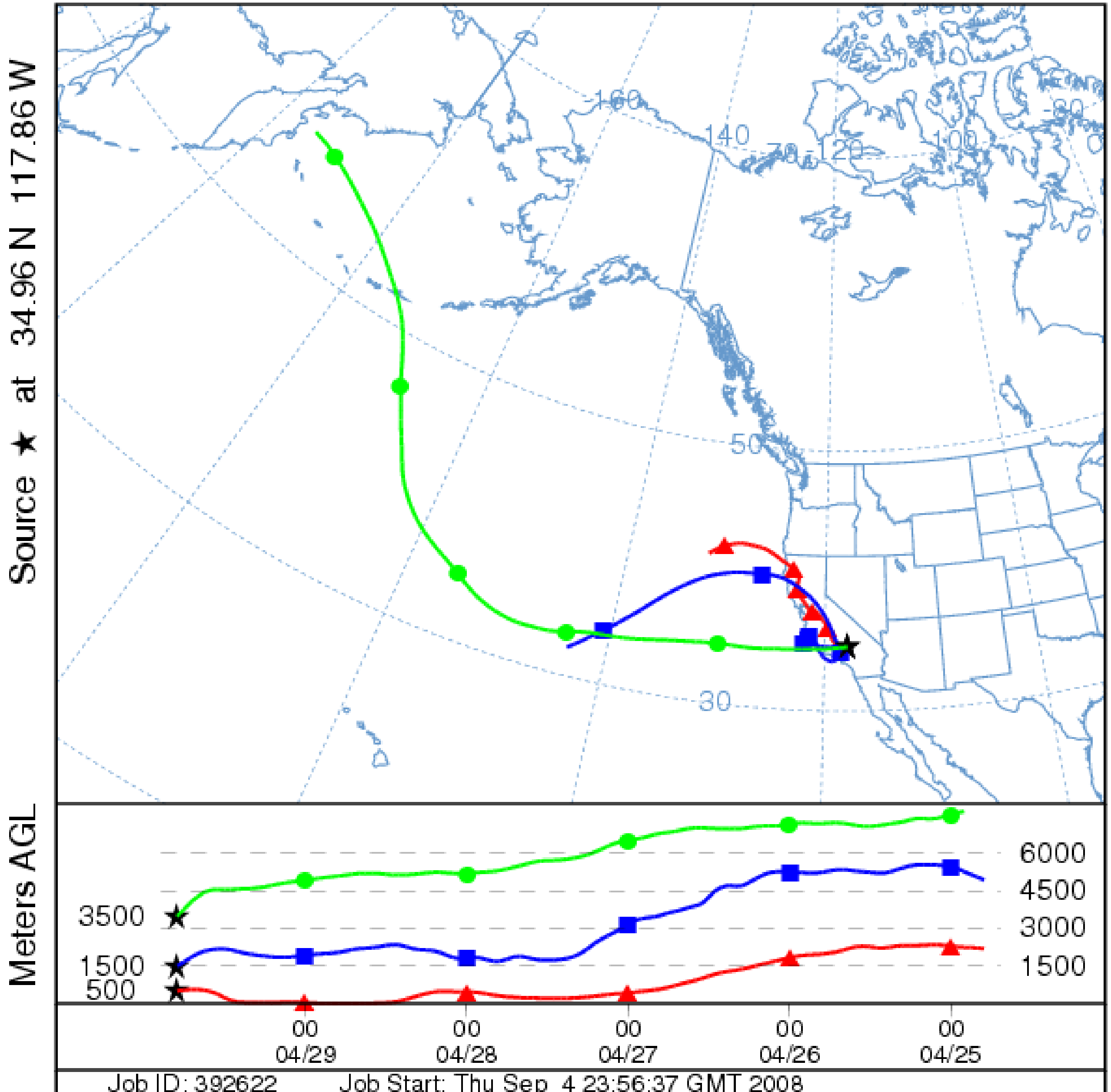
Black Carbon Concentration Vertical Profiles



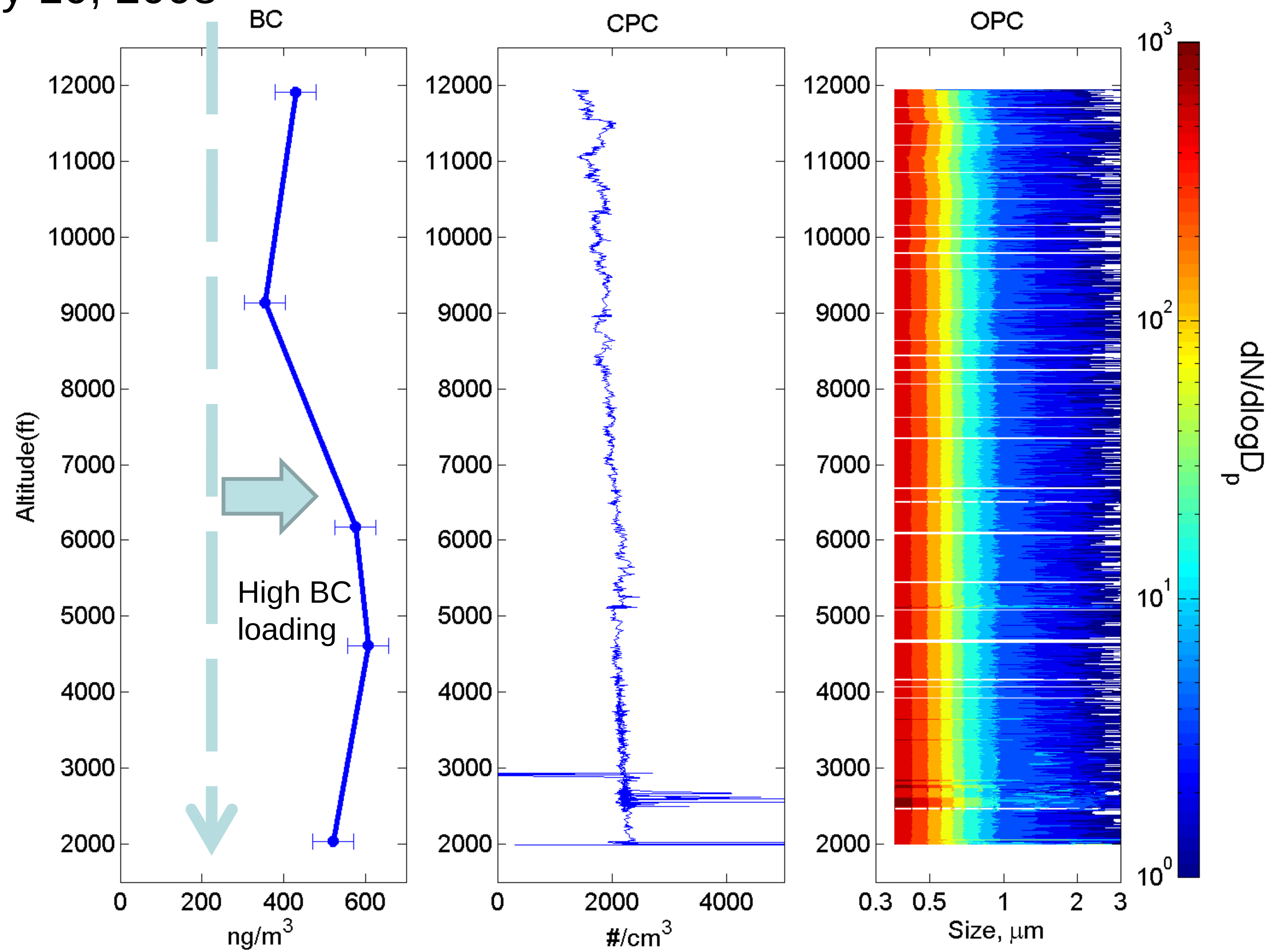
April 29, 2008



NOAA HYSPLIT MODEL
Backward trajectories ending at 19 UTC 29 Apr 08
GDAS Meteorological Data



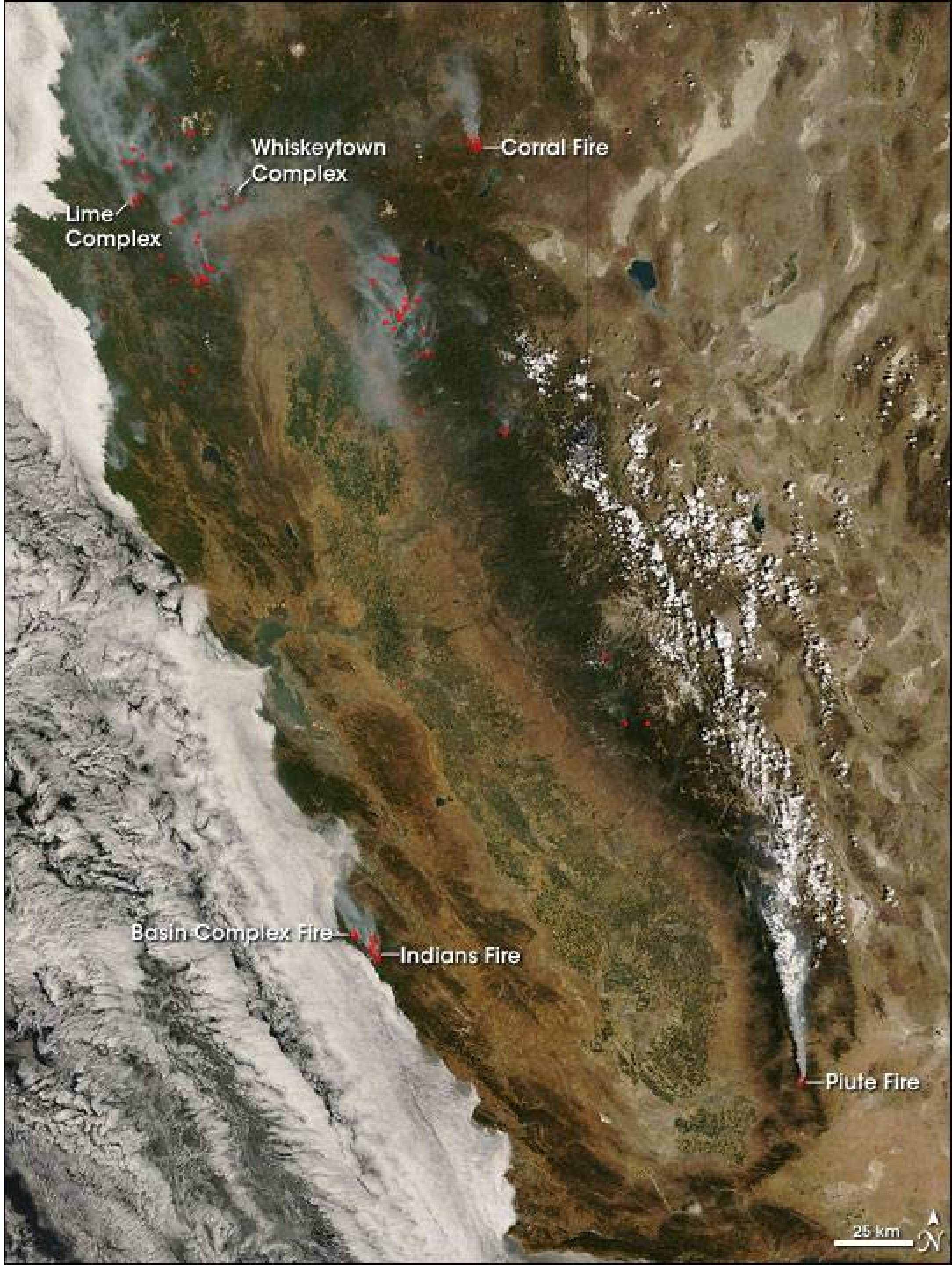
July 10, 2008



BC
CPC
OPC
Altitude(ft)
High BC
loading
ng/m3
#/cm3
Size, µm
dN/dlogDp

Wildfires are a significant local source of black carbon for summer and fall season.

Image from NASA Earth Observatory June30, 2008

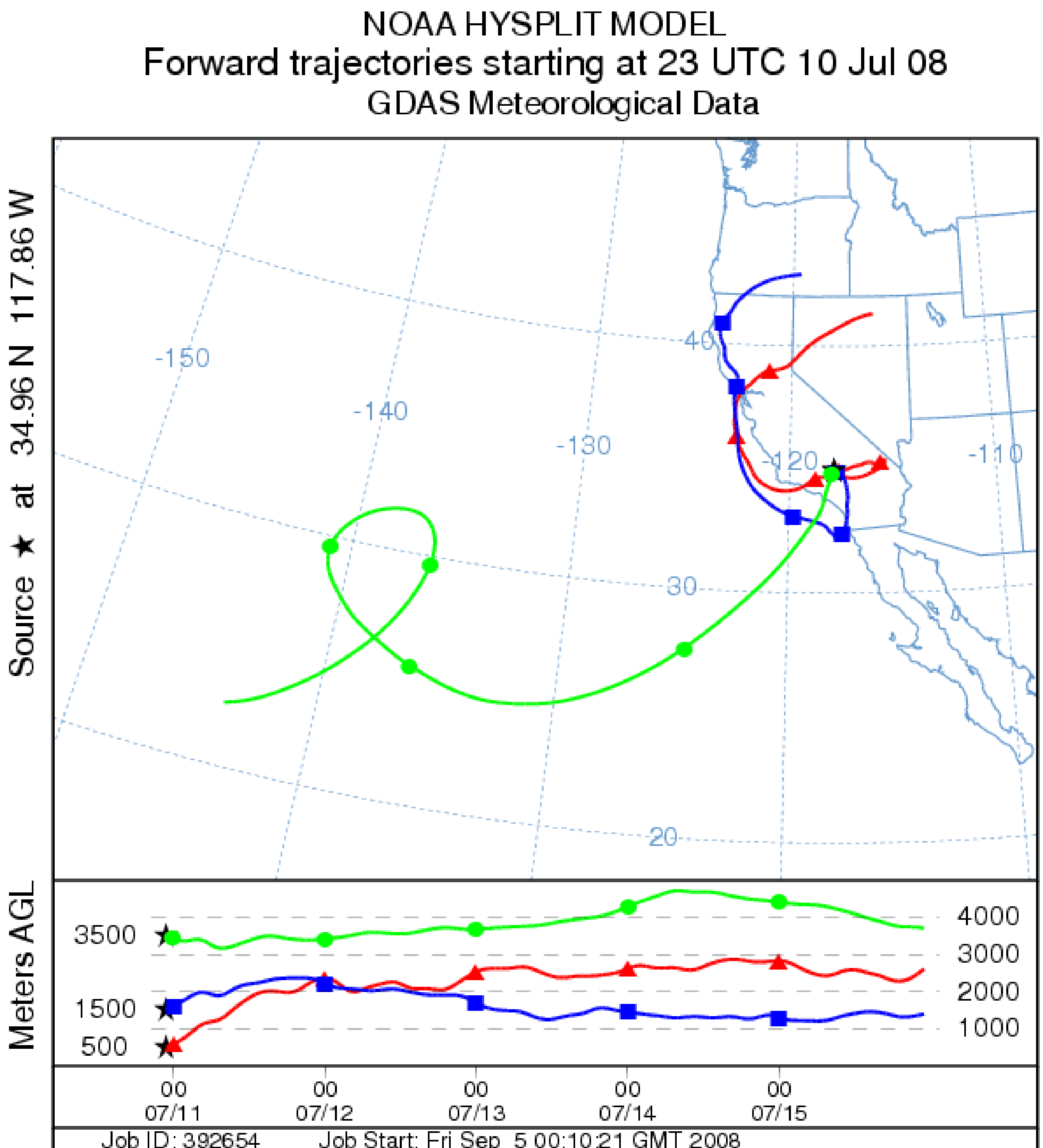


11 days later

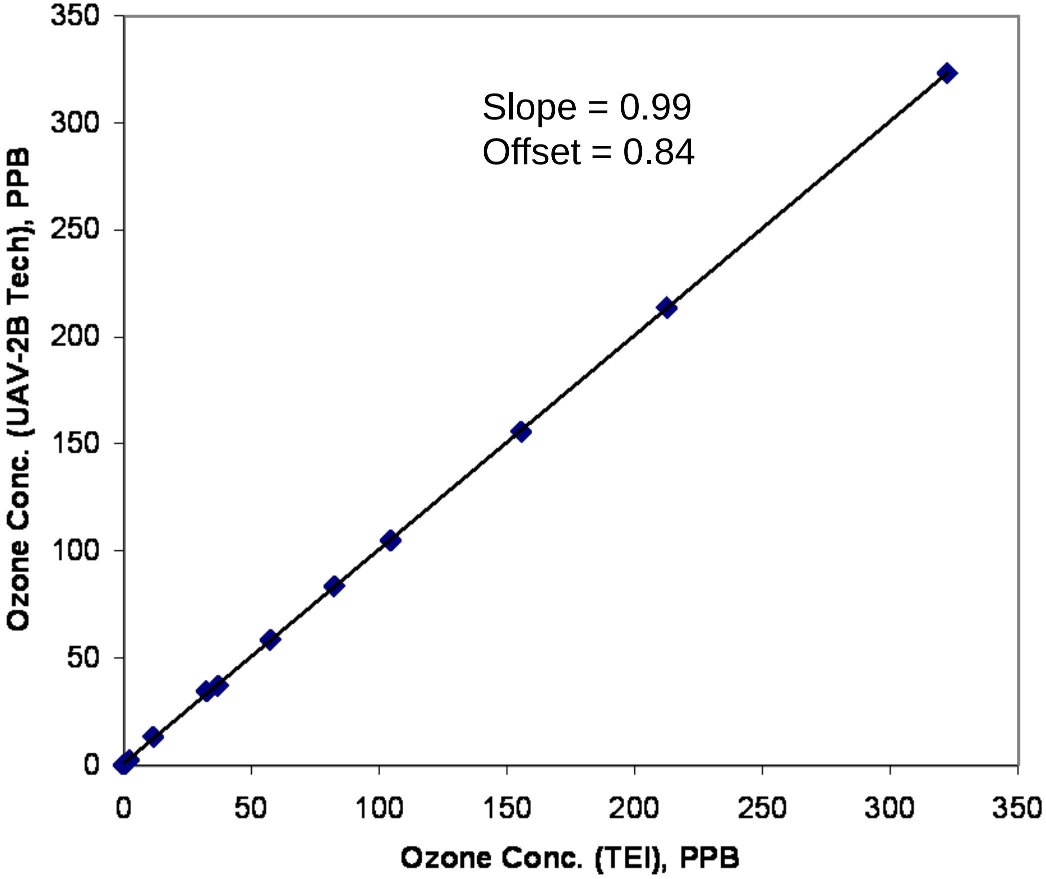
Image from NASA Earth Observatory July 10, 2008

Wildfire Near Flight Area

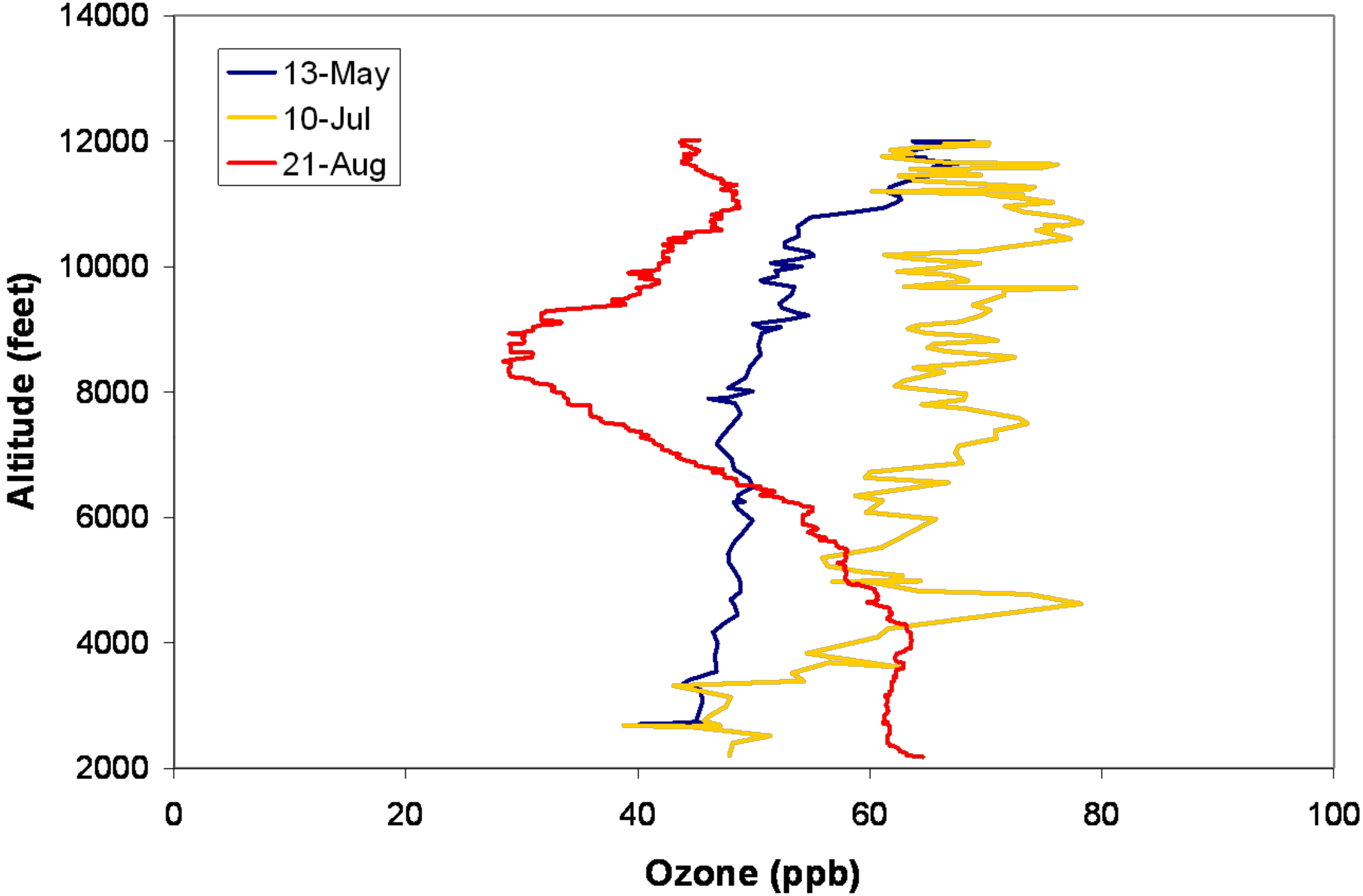
July 10, 2008


NOAA HYSPLIT MODEL
Forward trajectories starting at 23 UTC 10 Jul 08
GDAS Meteorological Data
Source ★ at 34.96 N 117.86 W
-150
-140
-130
-120
-110
40
30
20
Meters AGL
3500
1500
500
4000
3000
2000
1000
00 07/11
00 07/12
00 07/13
00 07/14
00 07/15
Job ID: 392654 Job Start: Fri Sep 5 00:10:21 GMT 2008

UAV Ozone Instrument



Ozone Concentration Vertical Profiles over NASA Dryden



Forcing and Heating Rates

Coming Soon

Summary

- Direct measurements are vital for understanding climate forcing and remote sensing and models.
- UAVs are a viable platform for making atmospheric measurements
- CAPPS project has collected measurements of aerosol and ozone profiles during the past 5 months.
- Analysis of heating rates are the next step.

Acknowledgments

Greg Roberts
MV Ramana
Katrin Lehmann
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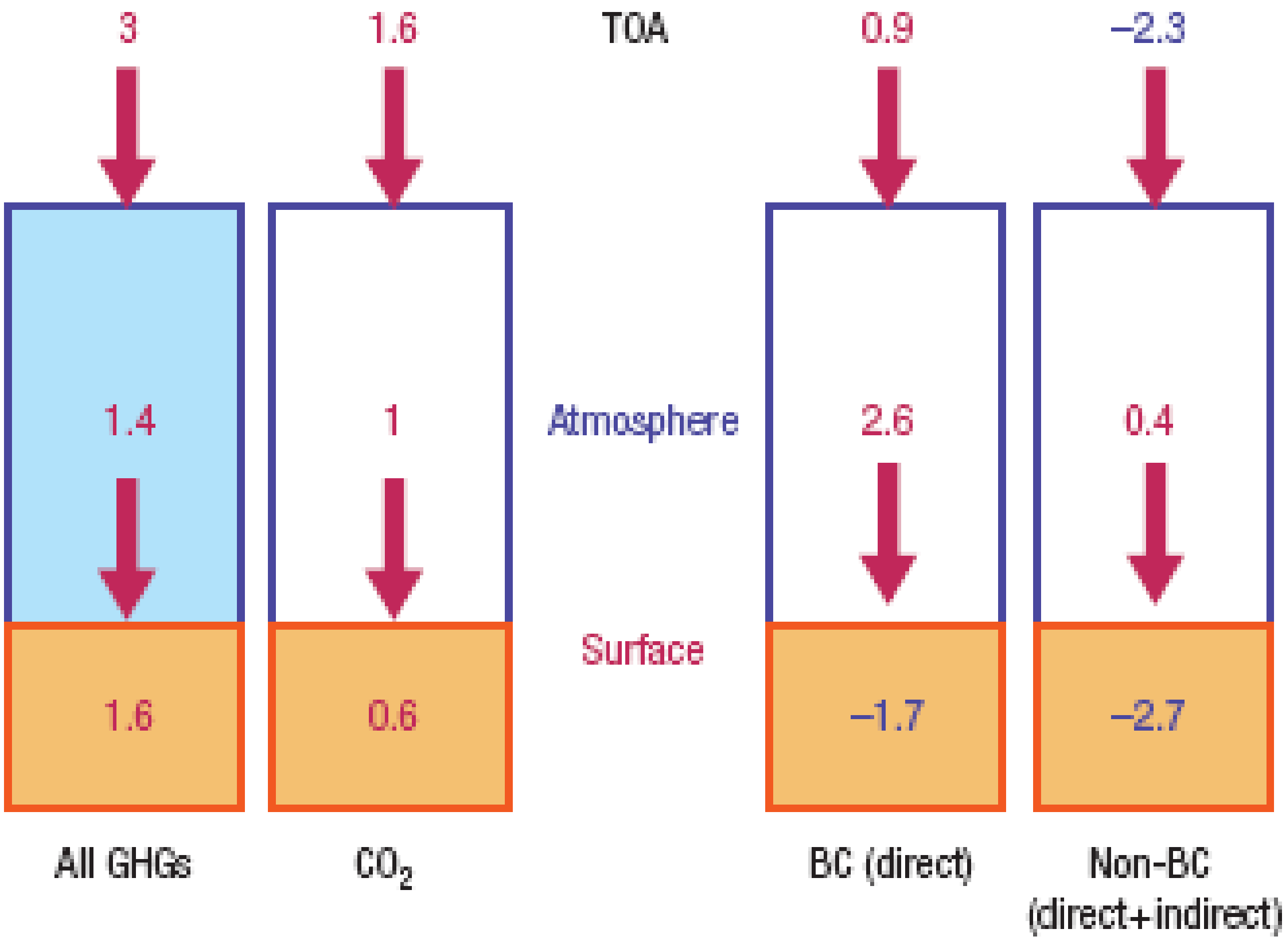
Odelle Hadley
California Energy Commission

Global Mean Radiative Forcing



Ramanathan and Carmichael, Nature 2008